MICE HYDROGEN SYSTEM

Operating Instructions

R&D version

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Change Record

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Preamble

This document is intended to be a record of the manual procedures required to operate the MICE Liquid Hydrogen System.

This version is explicitly for the R&D test programme only; Step IV operational instructions will evolve from this document.

The test programme will be deemed successful if liquid hydrogen is detected by the system's level sensor. Due to the uncertainty surrounding the hydride bed, the final volume of LH2 which will be collected cannot be predicted. The specific procedures to reach this point are as follows:

- Hall search and shift crew training *(Section 3)*
- Hydride bed charge *(Section 4.5)*
- Purge of H2 fill lines *(Section 4.2.3)*
- Purge of buffer tank *(Section 4.2.1)*
- Hydrogen fill sequence *(Section 4.6)*
- Hydrogen empty sequence *(Section 4.7)*
- Purge of buffer tank *(Section 4.2.1)*

The programme is expected to take 23 days; a 24 hour shift rota incorporating 17 days float has been finalised.

Please note that this document is necessarily a work-in-progress; please consult **Steve Watson** or **Phil Warburton** with any queries or comments (see Section 6.1 for contact details).

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System description

1.1 System design

The MICE Liquid Hydrogen (LH2) R&D system is designed to safely store hydrogen gas and deliver it to cryostat whereby a cryocooler will condense it into 22 litres of liquid hydrogen.

Gaseous hydrogen is stored in a **metal hydride bed**, itself contained within a sealed and ventilated enclosure (the **gas panel enclosure**). The hydride alloy absorbs hydrogen in an exothermic reaction, requiring cooling to continue the reaction. Heating of the bed creates an opposite endothermic reaction to evolve hydrogen. A precision **heater-chiller** unit provides the relevant temperature control. Evolving gas passes through a regulator and control valve, and then into a 1000 litre **buffer tank**, also within the gas panel enclosure. From here, the gas is transported outside the enclosure via a nitrogen-jacketed **transfer line** to a vacuum-jacketed **test cryostat**. A closed-cycle **cryocooler** cools a copper heater-exchanger, on which the hydrogen gas condenses to a liquid. The liquid collects in a 22 litre pot, representative of the eventual absorber pot which will reside with the MICE focus coil.

Gas delivery is managed in the gas panel using pneumatically-actuated ball valves. Each system operation is controlled using a pre-defined automated sequence. The control system uses an Omron PLC and a bespoke GUI.

The system is designed to DSEAR regulations, with intrinsic safety being the chosen ATEX protection method. The gas panel enclosure, ventilation system, vacuum pipework and vacuum pump enclosure are all designated as Zone 2.

1.2 Control system

1.2.1 Main screen

The main screen of the control system allows access to the different sequence screens and various control and data screens. Some screens are locked and require a password to access.

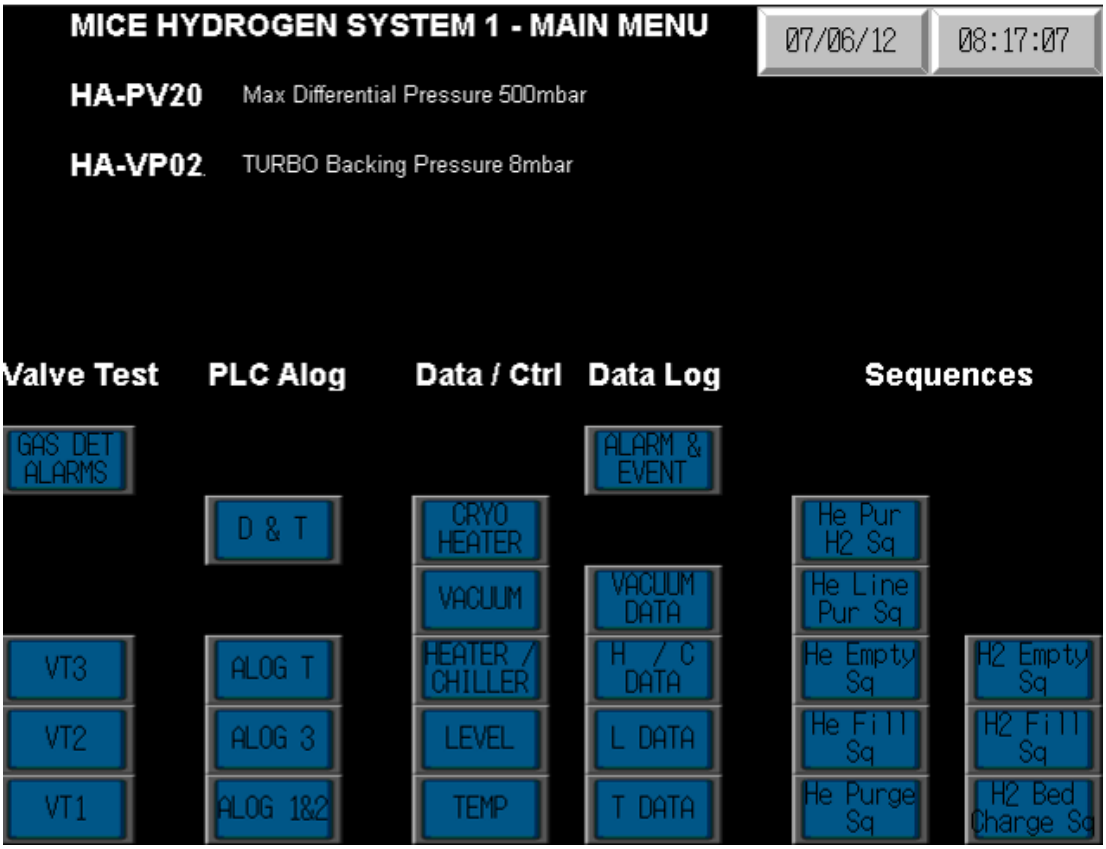


Figure 1: Control system - main screen

1.2.2 Sequence screens

The sequence screens allow the user to initiate automated sequences, as well as providing instructions for any manual intervention and checks required. To start a sequence requires a password.

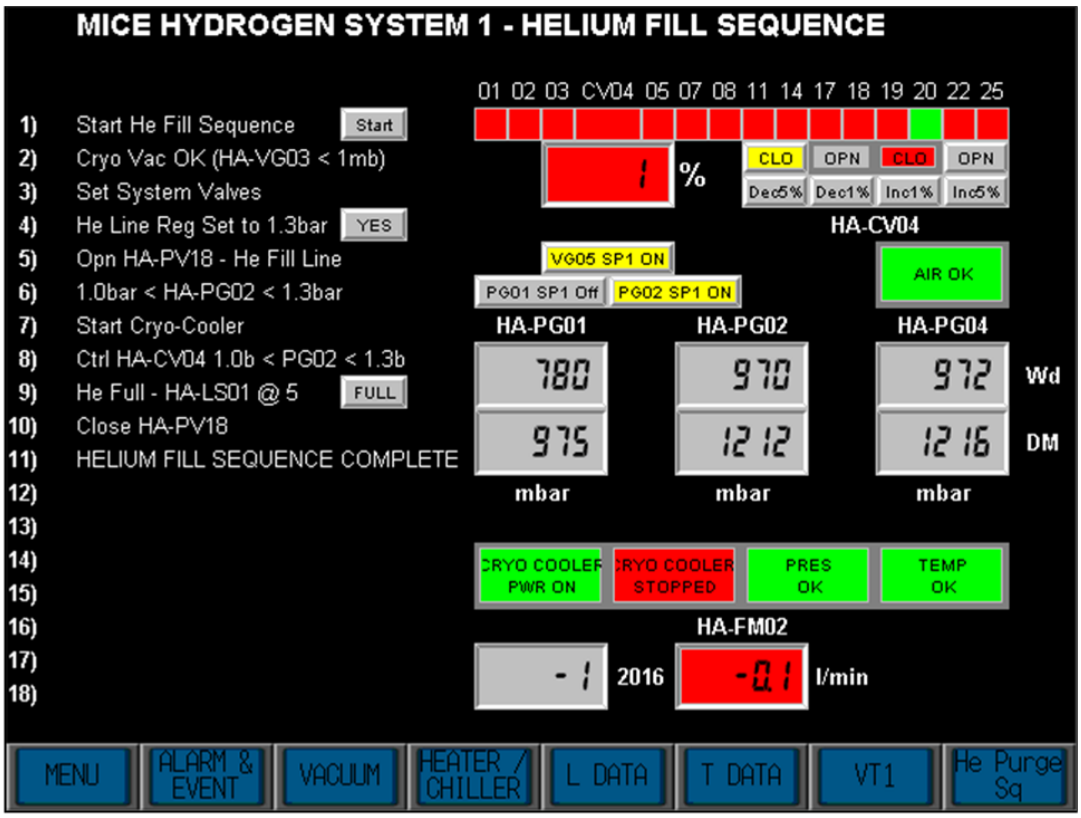


Figure 2: Control system - sequence screen example

1.2.3 Data screens

The data screens display sensor readings and graph them against time. Pressing will pause the graph and allow the user to scroll left to view the previous **24 hours**.

Data files are logged automatically every **24 hours**; pressing the button will interrupt the graph and download an intermediate data file to the logger.

There are 4 data screens; vacuum, level, temperature and heater/chiller. There are an additional 2 dedicated sensor readout screens for level and temperature.

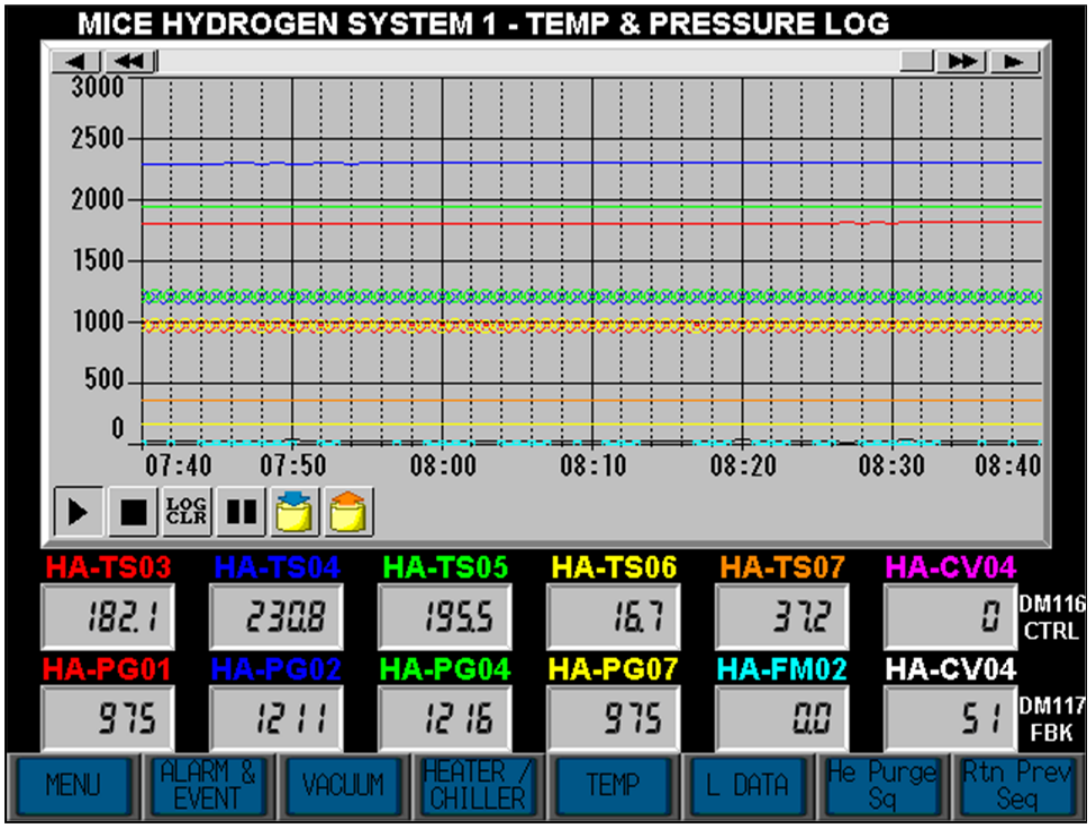


Figure 3: Control system - data screen example

1.2.4 Control screens

The control screens allow for manual control of various LH2 system components. They are used in commissioning and troubleshooting. The control screens operate outwith the predefined sequences and so are password protected.

There are 3 control screens; cryo heater, vacuum and heater/chiller (inc cryocooler controls).

There are also 4 valve test screens with which each individual valve setting can be controlled.

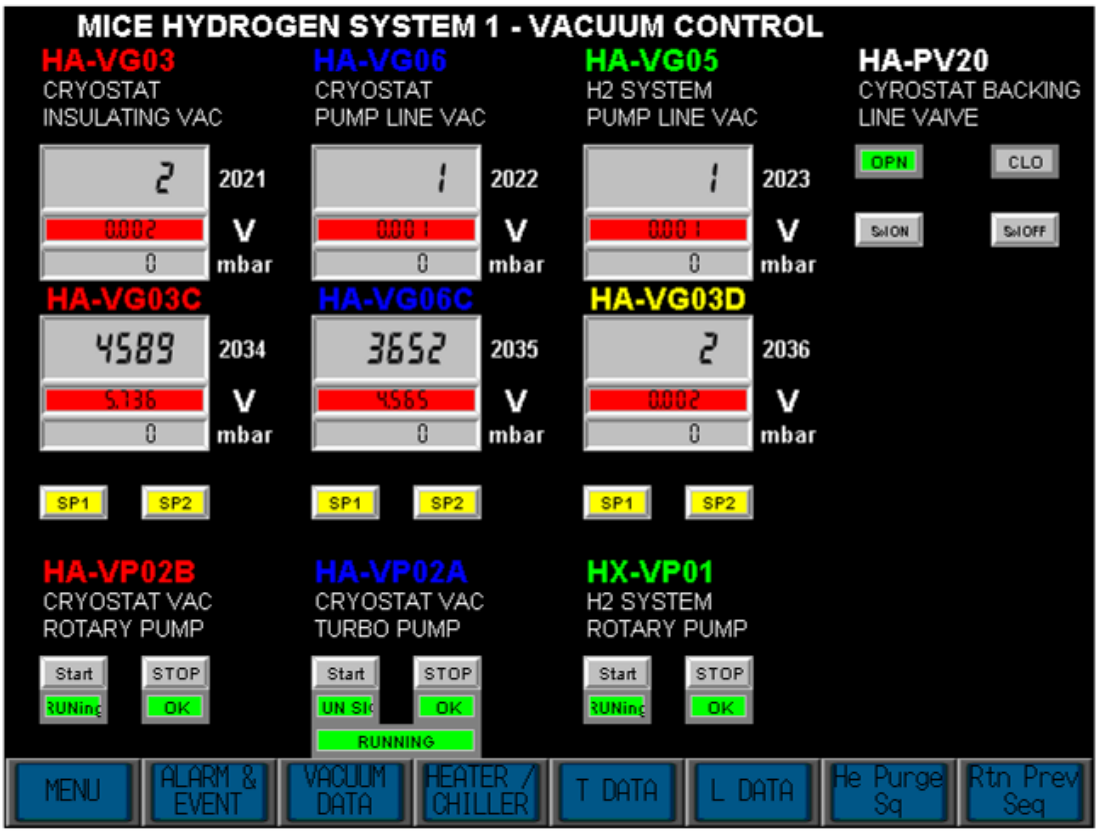


Figure 4: Control system - control screen example

1.3 Components list

1.3.1 Hardware

1.3.1.1 Cryostat

- **Cryostat** – designed and manufactured by AS Scientific.
  GA drawing: ***C0-14907***
- **Transfer line** – designed and manufactured by AS Scientific.
  GA drawing: ***C0-14922***
- **Cryocooler** – Sumitomo SRDK-415D
- **Cryocooler compressor** – Sumitomo CSW-71D

1.3.1.2 Gas panel

- **Gas panel enclosure** – designed and manufactured by AS Scientific.
  GA drawing: ***C0-15114***
- **Hydride bed** – Treibacher Auerstore MHS30000IHS
- **Buffer tank** – designed and manufactured by AS Scientific.
  GA drawing: ***C0-14908***
- **Pneumatic valves** – MARS 83 series
- **Control valve** – MARS 88 series
- **Pneumatic actuators** – Automax Super Nova SO63 S10 & SO85 S10
- **Relief valves** – Leser DZ/E-F-80
- **Rupture disks** – BS&B LPS
- **Check valves** – Swagelok SS-16C-VCR-1
- **Pipework** – designed and manufactured by AS Scientific.
  GA drawing: ***C0-16800***
- **Explosion relief panel** – design and manufactured by RAL.

1.3.1.3 Vacuum system

- **Backing pump** – Leybold TRIVAC D65B

- **Roughing pump** – Leybold TRIVAC D25B
- **Turbo pump** – Leybold TURBOVAC SL300
- **Gate valve** – VAT Series 48.2
- **Vacuum pipework** – Manufactured by AS Scientific

1.3.1.4 Ventilation system

- **Ventilation fans** – CFC CMV 450
- **Plenum** – Designed by RAL BPG, polypropylene construction
- **Bottle cabinet** – Designed by RAL BPG, polypropylene construction
- **Ductwork** – Designed by RAL BPG, polypropylene construction
  GA drawing: ***TD-1055-0896***
- **Dampers** – Greenbox GCD, ABS and PVC construction
- **Flame arrestors** – Elmac DFC

1.3.1.5 Purge gas supply

- **Regulator panels** – Designed and manufactured by Swagelok
  GA drawing: ***50995***
- **Supply regulators** – GCE Druva LMD 500

1.3.1.6 Heater-chiller

- **Heater-chiller** – Julabo LH50
- **Aux chiller** – Tool-Temp TT5000

1.3.1.7 Miscellaneous

- **UPS** – Riello Multi Plus 20kVA

1.3.2 Valve list

Table 1: Valve list

Identifier	Valve type	Description
PV01	Pneumatic valve	Hydride bed isolation valve
PV02	Pneumatic valve	H2 system isolation valve
PV03	Pneumatic valve	Buffer tank isolation-valve
CV04	Control valve	Buffer tank/hydride bed control valve
PV05	Pneumatic valve	Buffer tank/hydride bed relief valve isolation valve
RV06	Relief valve	Buffer tank/hydride bed relief valve (0.3bar differential)
PV07	Pneumatic valve	Buffer tank/hydride bed relief valve bypass valve
PV08	Pneumatic valve	Buffer tank relief line purge valve
BD09	Bursting disc	Buffer tank bursting disc (0.9bar differential)
RV10	Relief valve	Buffer tank relief valve (0.5bar differential)
PV11	Pneumatic valve	Cryostat relief line purge valve
BD12	Bursting disc	Cryostat bursting disc (0.9bar differential)
RV13	Relief valve	Cryostat relief valve (0.5bar differential)
PV14	Pneumatic valve	Hydrogen fill line isolation valve
HV15	Hand valve	Nitrogen bottle pack isolation valve
HV16	Hand valve	Helium bottle pack isolation valve
PV17	Pneumatic valve	H2 system vent line isolation valve
PV18	Pneumatic valve	Helium supply isolation valve
PV19	Pneumatic valve	H2 system purge pump isolation valve
PV20	Pneumatic valve	Cryostat gate valve
PV22	Pneumatic valve	Mass spectrometer port
RV23	Relief valve	Hydride bed relief-valve (30bar differential)
HV24	Hand valve	Hydrogen bottle isolation valve
PV25	Pneumatic valve	Vacuum poisoning isolation valve
NR26	Non-return valve	Back-flow protection for nitrogen purge line
NR27	Non-return valve	Pressure surge protection for buffer tank bursting disc
NR28	Non-return valve	Pressure surge protection for cryostat bursting disc
PR29	Pressure regulator	Pressure regulator to control hydride bed pressure
NR30	Non-return valve	Hydride bed return valve
HV31	Hand valve	Vacuum poisoning hand valve (lockable)
NR32	Non-return valve	Cryostat leak arrestor valve

BV33	Bottle valve	Nitrogen bottle pack valve
BV34	Bottle valve	Helium bottle pack valve
PR35	Pressure regulator	Pressure regulator to control nitrogen bottle pressure
PR36	Pressure regulator	Pressure regulator to control helium bottle pressure
PR37	Pressure regulator	Pressure regulator to control nitrogen pressure to system A
PR38	Pressure regulator	Pressure regulator to control helium pressure to system A
BV39	Bottle valve	Hydrogen bottle valve
PR40	Pressure regulator	Pressure regulator to control hydrogen bottle pressure
HV41	Hand valve	Hydrogen hand valve for System A
RV42	Relief valve	Hydride bed coolant circuit relief valve

1.4 System layout diagram

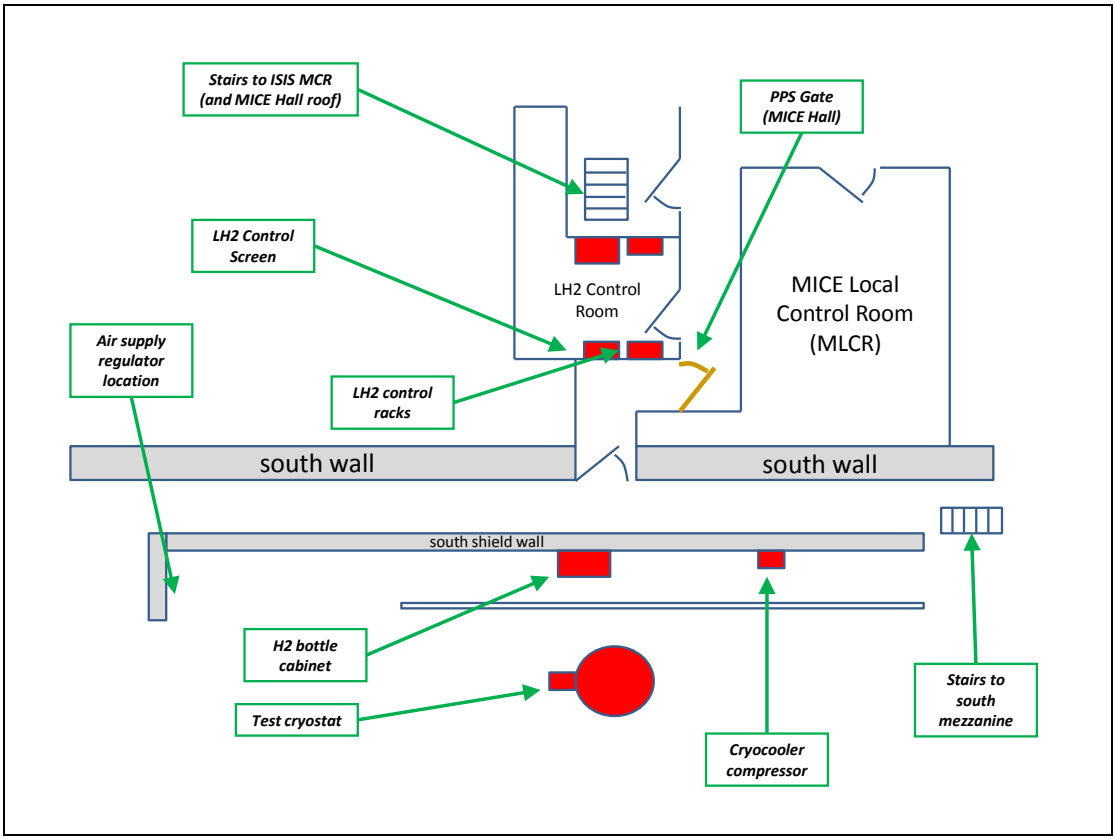


Figure 5: System layout - ground level

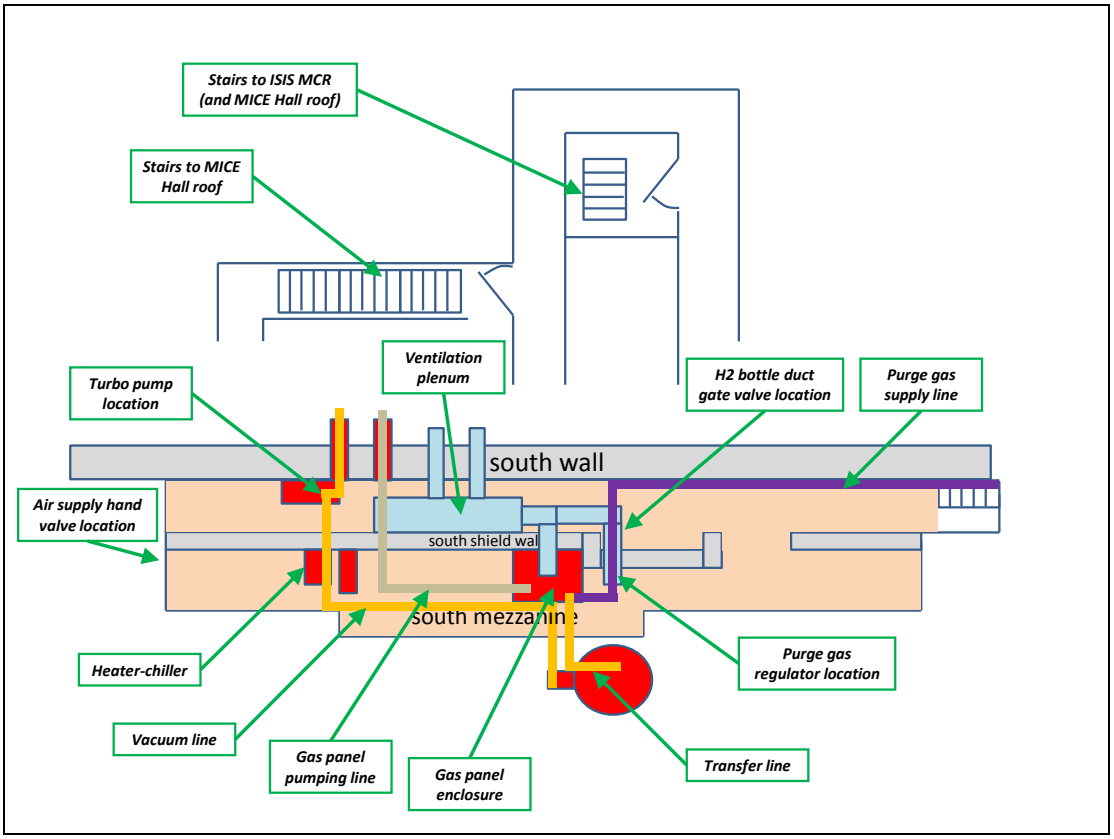


Figure 6: System layout - mezzanine level

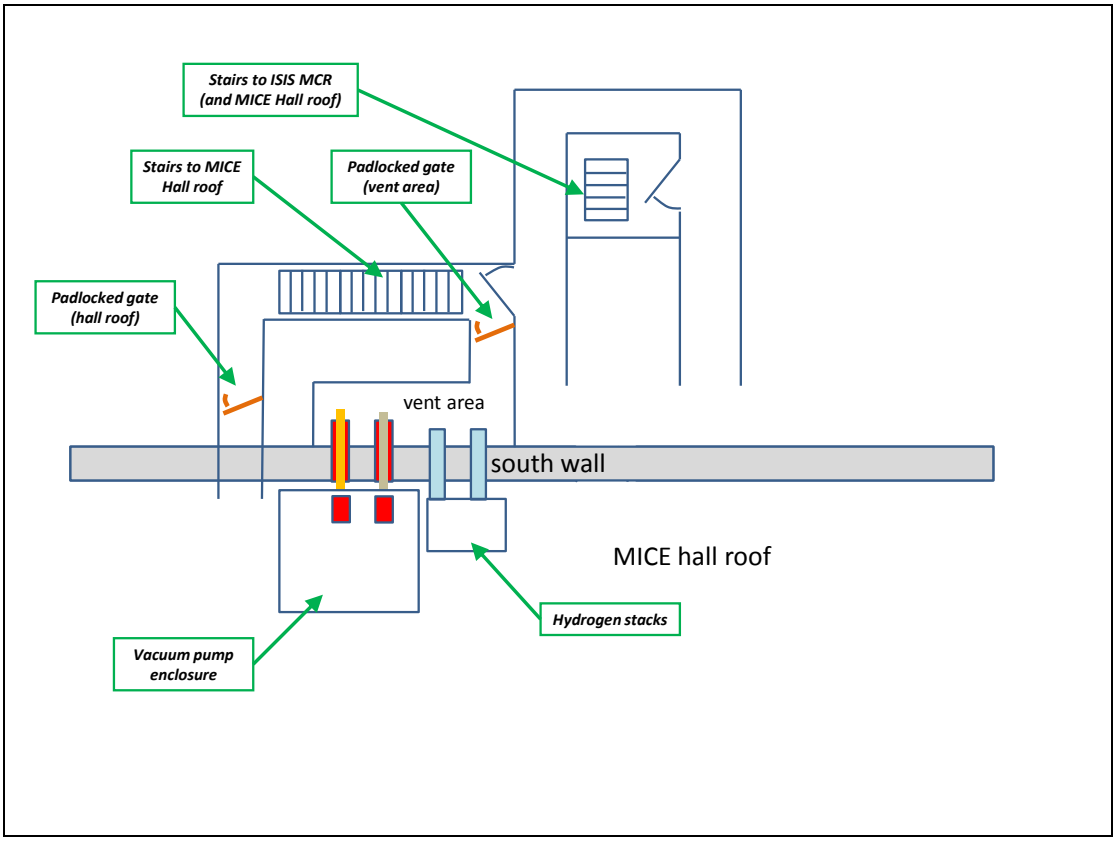
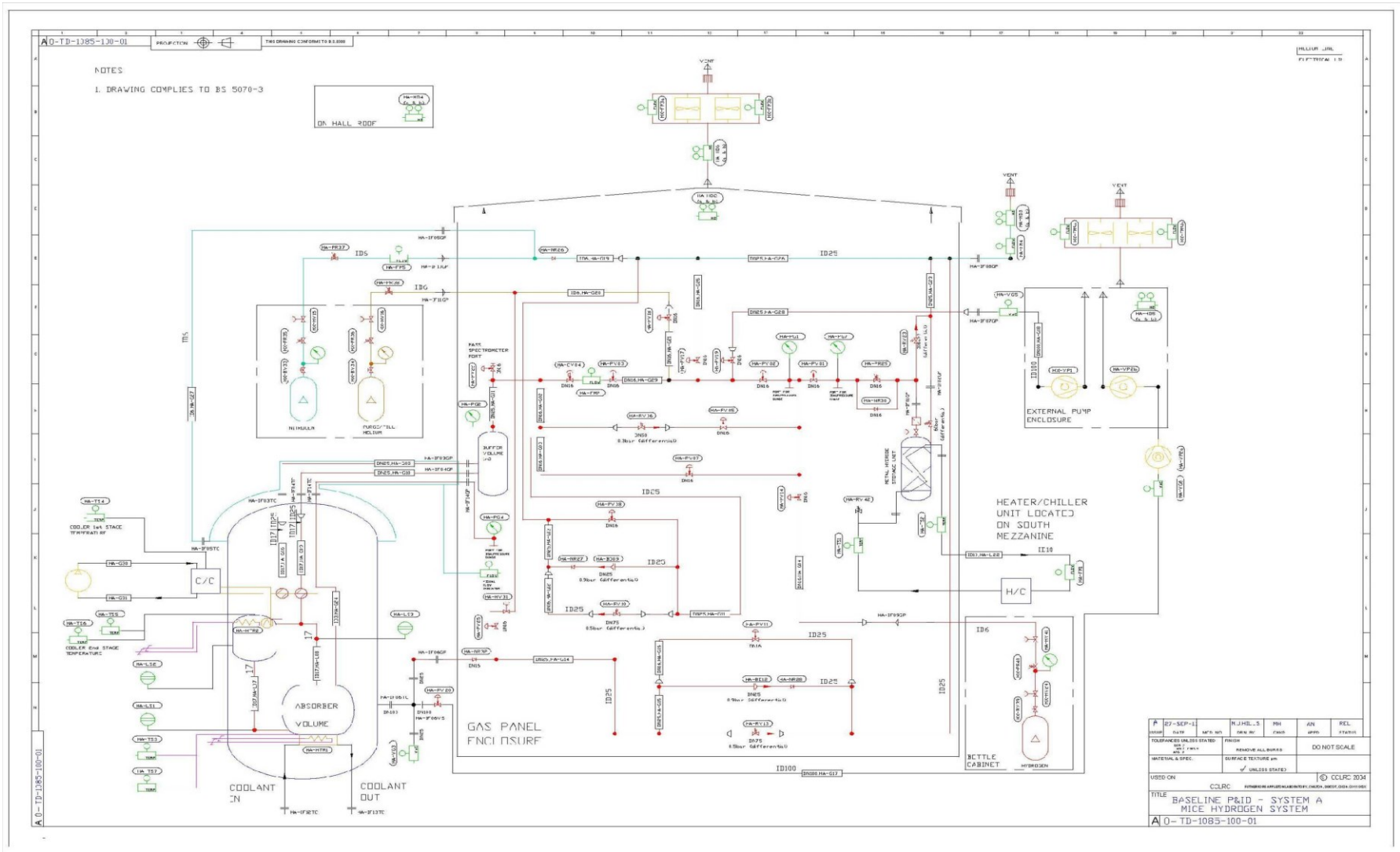


Figure 7: System layout - roof level

1.5 Piping and instrumentation diagram



2 System checks

System checks should be carried out prior to the initiation of any automated sequences. Where checks depend on whether 'hydrogen is to be used', this applies only to hydrogen external to the hydride bed.

Check lists can found in Section 7; these should be printed off and filled in where appropriate.

2.1 Control system and instrumentation

- Ensure the control panel is plugged in and responding.
- Ensure air supply to pneumatic valves is on by checking any of the automated sequence screens in the control panel and looking for a green button marked "AIR OK". If the button is red and displaying "AIR OFF", see Section 2.8 for instructions for how to switch on the air supply.
- Zero the flow total readout, if required, on the '*TEMP'* screen.

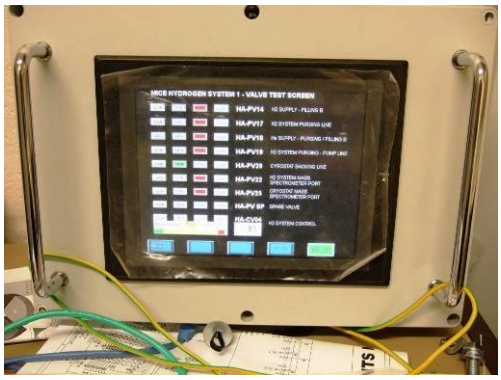


Figure 8: Control screen

- <u>If hydrogen is to be used</u> and the system vacuum is stable and less than **1x10-5 mbar**, ensure both Penning gauges (**VG03C** and **VG06C**) are unplugged and the gauge RJ45 port covered with tape.
- <u>If hydrogen is to be used,</u> only one resistor in each level sensor array should be energised. Contact **Phil Warburton** for further details.

2.2 Cryogenic system

- Visually check the cryostat, cryocooler, associated hoses and compressor for any loose fittings or damage.
- The cryocooler compressor pressure, shown on a dial on the compressor, should be **1.65 MPa** when off, and up to **2.2 MPa** when operating.
- Ensure that the cryocooler is ready to operate by checking that "CRYO COOLER PWR ON", "PRES OK" and "TEMP OK" on the '*HEATER/CHILLER'* screen.

Figure 9: Cryostat and compressor

2.3 Gas panel enclosure

- Ensure all sealed outer panels are in place and undamaged.
- Visually check air inlet filter, hydride bed burst panel and viewing port for any damage.
- Check that the vacuum poisoning hand valve (**HV31**) is open and padlocked. The valve is located at the base of the gas panel enclosure and can be seen through the viewing port.

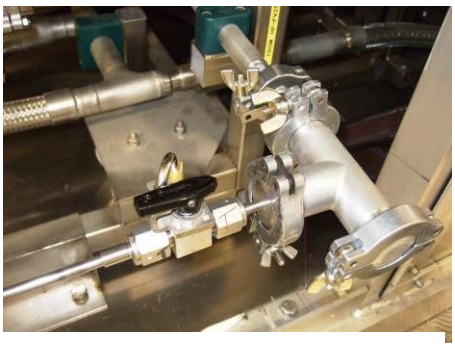


Figure 10: HV31 (vac poison valve)

2.4 Ventilation system

- Visually check all panels are in place, including the hydrogen bottle cabinet front panel and operating hatch, and all ductwork is undamaged.
- If hydrogen bottles are to be used, ensure the manually-actuated gate valve in the bottle cabinet ventilation ductwork is open. It is located on the south mezzanine, behind the shield wall (see Figure 6)
- If hydrogen bottles are not to be used, ensure the gate valve is closed.
- Ensure all the ventilation fans are operating as required:

- On the '*GAS DET ALARMS*' screen, the following boxes should be green:
  - 02.00, 02.01, 02.02 - Gas panel fan A
  - 02.03, 02.04, 02.05 - Gas panel fan B
  - 02.10, 02.11 - Vac pump enclosure fan A
  - 02.12, 02.13 - Vac pump enclosure fan B
- If the gas panel fans are not on, they can be switched on by pressing the green 'RUN' button on each respective control box, found in the LH2 control room.
- If the vac pump enclosure fans are not on, contact **Phil Warburton**, **Ian Mullacrane** or **Dave Matthewson** (x6210).

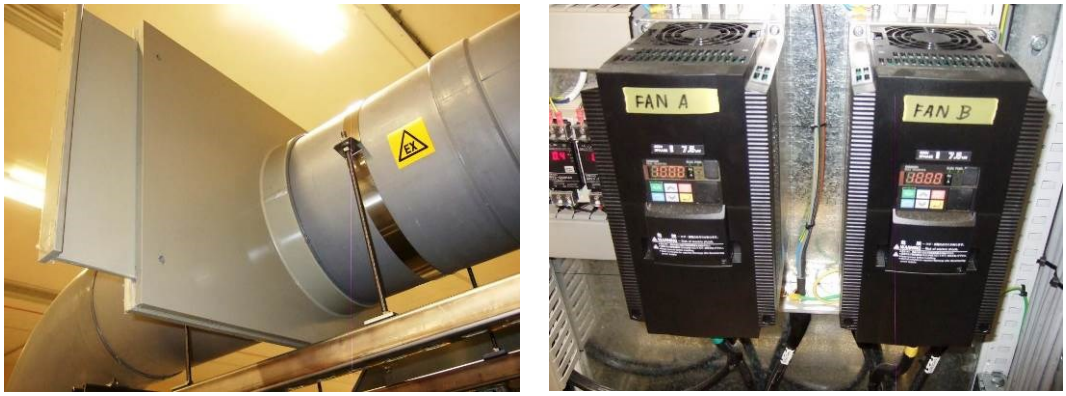


Figure 11: Ductwork gate valve and fan control boxes

2.5 Purge gas supply

- Check helium and nitrogen bottle pack pressures. The packs are found outside the MICE Hall equipment door. If either is below **100 barg**, consider changing pack before operating the system.
  - Both regulator panels incorporate changeover valves, so if two bottle packs are connected, this feature can be used. If only one pack is connected and the empty pack needs to be physically replaced, contact **Stewart Greenall** (x1309).

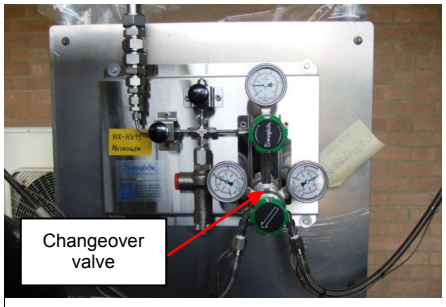


Figure 12: Purge gas regulator panel

- If the helium bottle pack is changed, a *Helium supply line purge ("He Line Pur Sq")* sequence must be run prior to any other operations.

- Set both nitrogen and helium bottle pack regulators (**PR35** & **PR36**) to around **3 barg**.
- Open the helium bottle pack isolation valve (**HV16**).
  - Check **PG01** on the '*CRYO HEATER*' screen reads **1350** - **1450 mbar**. If not, then:
    - Activate the **PV02 (VT) keyswitch.**
    - Close **all system valves** using the '*VT1*' and '*VT2*' screens.
    - Completely close the helium supply regulator (**PR38**) inside the hall (see Figure 6).
    - Use the '*VT1*' screen to momentarily open **PV17** to reduce the pressure to atmospheric. Ensure it is shut again before proceeding.
    - Open **PV18** and **PV02** are open by checking the '*VT1*' screen.
    - Slowly increase **PR38** such that **PG01** reads **~1450 mbar**.
    - Note that **PV18** is interlocked to a **PG01** reading of **1500 mbar**. If this is exceeded, the valve will close.
- <u>If hydrogen is to be used</u>, open the nitrogen supply hand valve (**HV15**).
  - Check **FM5** on the '*TEMP*' screen reads **~2 l/min**. If not, then:
    - Completely close the nitrogen supply regulator (**PR37**) inside the hall (see Figure 6).
    - Slowly increase **PR37** such that **FM5** reads approx **2 l/min**. The transfer line jacket flow indicator, located within the gas panel, should also read approx **2 l/min**.

Figure 13: Supply regulators (left; N2 [PR27], right; He [PR38])

2.6 Vacuum system

- Ensure the vacuum pump (**VP01** and **VP02B**) oil levels are within the required range as shown on the indicator.
- Check the current vacuum level in the cryostat on the Center 3 controller screens. If the respective gauges read as follows, the cryostat vacuum is OK. If not, continue with system checks and run a *Vac-down procedure [4.1]* as required:
  - **VG03C = <1x10^{-5} mbar**
  - **VG06C = <1x10^{-6} mbar**
- Check the turbo pump (**VP02A**) status is "STOPPED" and "OK" on the '*VACUUM*' screen. If it is showing "ERR", press "STOP" to reset the error. If this doesn't work, consult the manual.
- Ensure that the cryostat gate valve (**PV20**) is open on the '*VACUUM*' screen. If not, then:
  - Ensure that the turbo pump is "STOPPED" and the pressure differential between **VG03** and **VG06** is less than **100 mbar**. Open **PV20** by pressing "Sol ON" on the '*VACUUM*' screen.

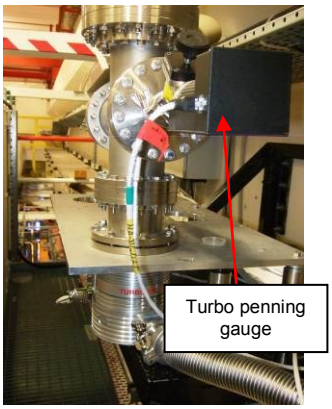


Figure 15: Turbo pump

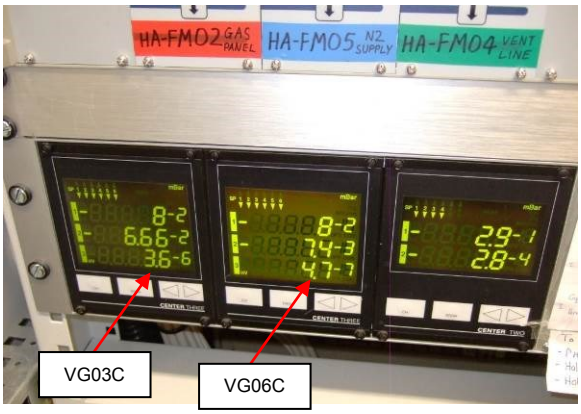


Figure 14: Center 3 controllers and turbo pump

2.7 Heater-chiller system

- If hydrogen is to be used, ensure the auxiliary chiller is on by checking the '*HEATER/CHILLER*' screen. If not, press "Start".
  - The unit set point temperature should be **18°C**. This can be checked and adjusted if necessary on the front of the unit itself.

- If the aux chiller is giving an alarm, it is likely to be due to low coolant level. Contact **John Govans** (x6012) to top up.

- If hydrogen is to be used, check the heater-chiller unit is ready to operate by checking the '*HEATER/CHILLER*' screen. If an "LH50 ALARM" is shown, check the screen on the front of the unit itself for the error code and consult the unit manual.
  - If a **Code 40** or **Code 14** alarm is shown on the unit, this indicates low liquid level; a relatively common problem. The coolant level can be topped up from the filler inlet on the front of the unit. Only Julabo Thermal H5 oil should be used; spare coolant is currently stored next to the unit.

    Do not top up with water.

Figure 16: Heater-chiller and auxiliary chiller

2.8 Services and ancillaries

- Compressed air supply to gas panel pneumatic valves is controlled by a hand valve and regulator. The hand valve is located at the east end of the south mezzanine (see Figure 6). The regulator is directly beneath the mezzanine floor (see Figure 5) and should be set to around **5 – 6 barg** or until the control panel reads "AIR OK".

Figure 17: Compressed air supply regulator

- The cryocooler compressor is plumbed into a central water supply, fed from a pump beneath the MICE hall. A flow gauge is located above the compressor; ensure that the flow is within the recommended limits indicated. If not, either adjust the flow using the hand valve next to the gauge, or contact **J. Govans** (x6012).

2.9 Miscellaneous

- Prior to any hydrogen operations:
  - Ensure all oxygen cylinders and oxy-acetylene sets have been removed from the MICE Hall prior to any hydrogen operations.

3 Access control and shift work procedures

3.1 Access control

There are three working areas with controlled access points (see Section 1.4):

- MICE Hall
  - PPS gate
- MICE Hall roof
  - Padlocked gate
- Vent area
  - Padlocked gate

3.1.1 Personnel Protection System (PPS)

Access to the MICE Hall is controlled using the PPS system. This system is uses a system of electromagnetic gates and personnel keys to control entry to the Hall but allow uninhibited emergency evacuation. A search procedure ensures that the Hall is evacuated prior to hydrogen operations and any unauthorised attempts at entry will drop the search, notifying the MICE LCR.

Figure 18: PPS main gate

3.1.1.1 PPS Search procedure

The MICE Hall, mezzanines, DSA and trench areas are searched by trained personnel, resulting in the PPS search being enabled. Note, Hydrogen Experts are <u>not</u> necessarily trained in the PPS Search procedure. The MICE Operations Manager (MOM) should be contacted if an unscheduled PPS Search is required.

Once the Search is enabled, the Hall can only be accessed using the Controlled Access procedure in Section 3.1.1.2.

3.1.1.2 Controlled Access procedure

The Controlled Access procedure allows operators to access the MICE Hall via the PPS gate without dropping the search.

<u>Two operators must be present to access the hall using this method</u>; one operator must remain in the MICE LCR to control the exterior electromagnetic lock.

- The entering operator should take the master key (**PK00**) from the LH2 control room key press.
- The remaining operator should press and hold the 'release gate' button on the PPS control box in the MICE LCR while the entering operator opens the door, enters the 'airlock' and then closes the door behind them. If the 'release' button is not held until the door is shut again, the Search will be dropped.
- Once inside the 'airlock', the entering operator should insert the door key, having removed it from the wall box, and insert key **PK00** in the personnel key box. A personnel key can then be removed and used to open the Yale lock on the inner door. The personnel key must be kept with the entering operator at all times.
- When exiting the Hall, the inner door can be opened using the Yale lock lever. Once inside the 'airlock', the entering operator should replace the personnel key and door key, remove **PK00** and contact the remaining operator via the intercom on the wall. The exterior door should then be opened using the same procedure as above.

Figure 19: PPS access control box

Figure 20: PPS key box and access control box

3.1.1.3 Dropped Search procedure

The PPS Search can be dropped for the following reasons:

- An erroneous Controlled Access attempt
- Unauthorised attempt to enter the Hall via any of the entrances
- Emergency exit from the Hall

If the Search is dropped by a mistake made during a Controlled Access attempt and the remaining operator is sure of this; the Controlled Access can go ahead as planned. Once the entering operator has exited the Hall, **PK00** should be locked in

the LH2 keypress and no further Controlled Access is permitted until the Search has been enabled again.

If the Search is dropped for any other reason, **PK00** should be locked in the LH2 keypress and no Controlled Access permitted until the Search has been enabled again.

3.1.2 Keys

Access to the MICE Hall roof and vent area are restricted with padlocks.

Padlock keys are held in the LH2 keypress, situated on the wall of the LH2 control room. Keys for keyswitches and various lockable valves are also held in the keypress. Where applicable, spares are held by **Stewart Greenall**.

Figure 21: LH2 keypress

3.1.2.1 Keyswitches

Certain system valves have keyswitches (located on the LH2 control rack) to override interlocks and enable manual operation.

Table 2: Keyswitches

Keyswitch	Action / required when	Key tag number
PV01	H2 operation permit Required in H2 fill/empty and hydride bed charge	11
PV02	Manual control enable Required to manually operate valves	12
PV19	PV19 interlock override Required for He line purge	13
PV20	PV20 interlock override Required to open PV20 when VP02B off	14
PV14	PV14 keyswitch Required for hydride bed charge	15
PV22	PV22 keyswitch Required to open mass spec port	17
PV25	Vacuum poisoning switch Shuts PV20, opens PV25 until VG03 = 1 mbar	18

3.2 Shift work procedures

During hydrogen operations, there will be a 24 hour shift rota in place. The rota incorporates two operators where possible as entry to the MICE Hall will generally be necessary.

The 24 hour period is broken up into six 4 hour shifts, working in a staggered pattern to create overlap between shifts. This means no official handover is required between changing shift workers.

Direct shift worker instructions are provided in the Appendices (Section 7).

3.3 Interaction with ISIS MCR

The ISIS Main Control Room and shift crew do not have any direct association with MICE. However, due to its proximity to the MICE Hall, the MCR should be kept informed of all and any alarms and faults. Shift workers should also provide regular progress updates to the MCR.

The ISIS shift crew may need to enter the MICE Hall at short notice. If this occurs during PPS Controlled Access mode, the ISIS crew member will contact the LH2 control room for access. If this happens, the MICE operator must not restrict access to the Hall unless there is a clear safety risk.

3.3.1 Evacuation procedure

If a consensus is reached between MICE LH2 experts and the ISIS MCR that the risk of an unforeseen and catastrophic hydrogen incident is heightened and developing, evacuation must be considered. In this scenario, the **nearest fire alarm should be activated**. The alarm should only be silenced once a Hydrogen Expert has determined that the risk level has dropped.

It must be stressed that the decision to sound the fire alarm must include input from the ISIS MCR.

Some ISIS MCR personnel may remain in the MCR as it is an essential site communications hub. This will be at their own discretion.

The RAL site Alarm Investigation Team (AIT) should be contacted and liaise with the MICE team to clarify the situation.

Security should be asked to inform the Site Emergency Controller.

4 Operating procedures

4.1 Vac-down procedure

The vac-down procedure creates a high-vacuum in the insulating volume in the cryostat.

- Start the backing pump (**VP02B**) by pressing the relevant "Start" button on the '*VACUUM*' screen.
- When **VG06** is less than **1 mbar**, start the turbo pump (**VP02A**) by pressing the relevant "Start" button on the '*VACUUM*' screen.
- When **VG03B** and **VG06B** drop below **1x10^{-2} mbar**, the respective Penning gauges will switch on.
- When **VG03C** reads less than **1x10^{-5} mbar**, the system is ready for cryogenic operation.

4.2 Purge procedures

4.2.1 Standard helium purge ("He Purge Sq")

A standard helium purge clears the buffer tank, absorber pots and delivery pipework of contaminants.

- Fill out **Pre-system check list 1**.
- The helium purge sequence is initiated from the '*He Purge Sq'* screen.
- Press the "START He PURGE" button at the top of the screen.
- The system will ask for a password and request confirmation that the helium bottle pack isolation valve (**HV16**) is open.
- The system will request confirmation that the purge pump (**VP01**) is on; if not, start it using the "Start" button provided.
- The remainder of the sequence will complete automatically. The system is left pressurised with helium.

4.2.2 Helium supply line purge ("He Line Pur Sq")

A helium supply line purge clears the pipework from the helium bottle pack of contaminants. This sequence does not purge the buffer tank or absorber.

Note, this sequence requires manual operation of a bottle hand valve. Two operators with walkie-talkies is recommended.

- Fill out **Pre-system check list 1**.
- The helium supply line purge sequence is initiated from the '*He Line Pur Sq*' screen.
- Press the "START He LINE PURGE" button at the top of the screen.
- The system will ask for a password and request confirmation that the helium bottle valve (**BV34**) is closed, the helium bottle pack isolation valve (**HV16**) is open and the **PV18 override key** has been activated.
- The system will request confirmation that the purge pump (**VP01**) is on; if not, start it using the "Start" button provided.
- The line is pumped down.
- The system will request that **BV34** is opened. This must be done manually on the helium bottle pack itself. The line is pressurised[1].
- The system will then make two further requests for **BV34** to be closed and opened, ultimately leaving the system pressurised with helium.

4.2.3 Hydrogen-side purge ("He Pur H2 Sq")

A hydrogen-side purge gives the user the option of clearing either the pipework downstream of the hydrogen fill line isolation valve (**PV14**) or the hydride bed isolation valve (**PV01**) of contaminants; the sequence will not allow both options to be selected as this would create the risk of an open hand valve on the hydrogen bottle regulator panel admitting air into the hydride bed. This sequence does not purge the buffer tank or absorber.

- Fill out **Pre-system check list 2**.
- The hydrogen-side purge sequence is initiated from the '*He Pur H2 Sq*' screen.
- Press the "START He PURGE H2 SIDE" button at the top of the screen.
- The system will ask for a password and request confirmation that the helium bottle pack isolation valve (**HV16**) is open.
- The system will request confirmation that the purge pump (**VP01**) is on; if not, start it using the "Start" button provided.

[1] At this point, the helium supply regulator pressure (**PR38**) can checked and reset accordingly. See Section 1.3.1.5.

- The system will request confirmation that the line downstream of **PV14** is to be purged.
    - If "Yes" is selected, the system will request that the **PV14 override key** is activated.
- The system will request confirmation that the line downstream of **PV01** (potentially including the hydride bed) is to be purged.
    - If "Yes" is selected, the system will request that the **PV01 override key** is activated.
- The remainder of the sequence will complete automatically. The system is left pressurised with helium.

4.3 Helium fill

The helium fill sequence liquefies helium by pressurising the closed cryogenic circuit with warm helium to **1.15 bar**, allowing the pressure to drop due to cooling by **0.1 bar**, then pressurising again.

- Fill out **Pre-system check list 1**.
- Run the *Vac-down procedure [4.1]* if necessary.
- Run a *Standard helium purge ("He Purge Sq") [4.2.1]* if necessary.
- The helium fill sequence is initiated from the '*He Fill Sq'* screen.
- Press the "Start" button at the top of the screen.
- The system will ask for a password and request confirmation that the helium bottle pack isolation valve (**HV16**) is open.
- The system will request confirmation that the helium supply regulator is set to the correct value.
- The system will begin the cooldown and liquefaction of helium. Once cold, the absorber fills at approximately **0.5 L/day**; a complete fill will take approx **45 days**.
- The user can interrupt the sequence by pressing the "FULL" button at any time. This will close the helium supply valve but keep the cryocooler operating.
- If the user does not interrupt the sequence, the helium level will eventually reach the recondensing heat exchanger, at which point no more helium can be liquefied.

4.4 Helium empty

The helium empty sequence operates the absorber pot heaters to boil off any liquid and release the gas into the vent lines.

- Fill out **Pre-system check list 1**.
- The helium empty sequence is initiated from the '*He Empty Sq'* screen.
- Press the "Start" button at the top of the screen.
- The system will ask for a password.
- The system will begin a heater control loop to boil off liquid helium and release the gas into the vent lines.
- Once the absorber temperature (**TS03**) reaches **70K**, the heaters switch off.
- The user can end the sequence by pressing the "Empty" button. This will close the vent line isolation valve (**PV17**).

4.5 Hydride bed charge

4.5.1 Bed connection

The bed connection procedure is a one-off procedure for opening the hydride bed hand valve for the first time.

- The hydride bed is stored pressurised with argon gas to prevent air leakage into the unit.
- A *Hydrogen-side purge ("He Pur H2 Sq") [4.2.3]* should be initiated with the user answering "YES" to **Step 7**. This will purge the line upstream of the hydride bed isolation valve (**PV01**) of air. The sequence finishes by pressurising the system to **1.1 bar** helium and isolating the hydride bed.
- The hydride bed hand valve can now be opened

4.5.2 Charging procedure

The charging procedure is a complex operation with manual and automatic elements. Anti-static clothing must be worn during this procedure and only non-sparking tools should be used.

- Fill out **Pre-system check list 3.**

Stage 1: Bottle positioning

- Two hydrogen bottles are stored in a standard bottle rack outside the main MICE Hall door.

- Ensure the hand valve is tightly closed before moving a bottle. Check that the route to the charging station via the main door is clear of obstacles and that the charging station front panel has been removed, ready to receive the bottles.
- The bottles should be carefully secured on to a four-wheeled bottle trolley and moved into the Hall. The bottles should be brought to the charging station via the ramp beneath the south mezzanine.
- Each bottle should be positioned on one of the racks within the charging station, fastened with the chain and rotated such that the valve connection faces the regulator. Do not connect the bottles.

Stage 2: System preparation

- The MICE Hall should be placed under controlled access, using the PPS search procedure (see Section 3.1). This will prohibit access to the Hall via the equipment door and control access via the main door.
- Manually confirm that the ventilation system is operating as expected (see Section 2.4).

Stage 3: Bottle connection

- Connect the pigtail bottle connection to the bottle valve. Note, POL adaptors for hydrogen bottles are left-hand thread.
- Once both bottles are secured and connected, replace the charging station front panel. Do not open the hydrogen bottle valves once connected.
- Open both hand valves on the hydrogen bottle regulator panel (**HV24** and **HV41**) and fully open the regulator (**PR40**). Again, do not open the hydrogen bottle valves.

Stage 4: Pre-purges

- A *Standard helium purge ("He Purge Sq") [4.2.1]* should be run.
- A *Hydrogen-side purge ("He Pur H2 Sq") [4.2.3]* with **PV14** open and **PV01** closed should be run.
- A *Hydrogen-side purge ("He Pur H2 Sq") [4.2.3]* with **PV01** open and **PV14** closed should be run.

Stage 5: Charging sequence

- The bed charge sequence is initiated from the '*Bed Charge Sq*' screen.
- Press the "Start" button at the top of the screen.

- The system will ask for a password and will check that the nitrogen flow is sufficient (**FM05**).
- The heater-chiller will be set to '**absorb**' mode with an enforced **5 minute** pause.
- The system will request confirmation that the purge pump (**VP01**) is on; if not, start it using the "Start" button provided.
- **PV19** opens and the hydride bed and connecting pipework is evacuated.
- The system will request that the user opens the hydrogen bottle valves and respective hand valves:
    - Close all hand valves (**HV24** and **HV41**) and the regulator (**PR40**) on the regulator panel.
    - Open both hydrogen bottle valves (**BV39**) fully.
    - Open both pre-regulator hand valves (**HV24**) and check that the regulator upstream pressure is as expected.
    - Open both post-regulator hand valves (**HV41**).
    - Slowly open the regulator (**PR40**) until the downstream pressure is **1.5 bara**.
- Continue the control sequence by pressing "OK". The sequence will open PV14 and begin to charge the hydride bed.
- The regulator upstream pressure should be checked every **30 minutes**. Once the bottle pressure stabilises or **8 hours** is shown on the control screen counter, press "Ch" on the sequence screen.
- The system will request that the user closes the hydrogen bottle valves but leave all other valves open. Press "Bottle Closed" to continue the sequence.
- A *Hydrogen-side purge ("He Pur H2 Sq") [4.2.3]* with **PV14** open and **PV01** closed will automatically be initiated. It is likely that a hydrogen detector alarm in the vac pump enclosure will sound during this sequence; see Section 5.2 for instructions.
- Once the purge has been completed, the hydrogen bottles can be removed using the same process described in **Stage 1** above.

4.6 Hydrogen fill

The hydrogen fill sequence liquefies hydrogen by pressurising the closed cryogenic circuit with warm hydrogen to **1.15 bar**, allowing the pressure to drop due to cooling by **0.1 bar**, then pressurising again.

- Fill out **Pre-system check list 2**.
- Run the *Vac-down procedure [4.1]* if necessary.
- Run a *Standard helium purge ("He Purge Sq") [4.2.1]* if necessary.
- The hydrogen fill sequence is initiated from the '*H2 Fill Sq'* screen.
- Press the "Start" button at the top of the screen.
- The system will ask for a password and will check that the nitrogen flow is sufficient (**FM05**).
- The heater-chiller setpoint will be set to '**evolve**' mode and hydrogen will begin to be liberated from the hydride bed.
- The system will begin the cooldown and liquefaction of hydrogen. Once cold, the absorber fills at approximately **1.5 L/day**; a complete fill will take approx **15 days**.
- The user can interrupt the sequence by pressing the "FULL" button at any time. This will cause the heater-chiller to be set to '**absorb**' mode and will reroute the path from absorber to hydride bed through a relief valve.
- If the user does not interrupt the sequence, the hydrogen level will eventually reach the recondensing heat exchanger, at which point no more hydrogen can be liquefied.

4.7 Hydrogen empty

The hydrogen empty sequence operates the absorber pot heaters to boil off any liquid and return the gas to the hydride bed.

- Fill out **Pre-system check list 2**.
- The hydrogen empty sequence is initiated from the '*H2 Empty Sq'* screen.
- Press the "Start" button at the top of the screen.
- The system will ask for a password and will check that the nitrogen flow is sufficient (**FM05**).
- The hydride bed relief valve bypass valve (**PV07**) is opened and the heater-chiller is set to '**absorb**' mode.

- The system will begin a heater control loop to boil off liquid hydrogen and return gas to the hydride bed.
- Once the absorber temperature (**TS03**) reaches **30K**, the heaters switch off.
- Once **TS03** reaches **100K** and the buffer tank pressure is **0.1 bara**, the hydride bed isolated valve (**PV01**) is closed.
- A *Standard helium purge ("He Purge Sq") [4.2.1]* will automatically be initiated.

5 Fault procedures

All fault procedures require the input of Hydrogen Experts and no action should be taken by non-experts other than to contact a Hydrogen Expert and inform the ISIS MCR.

Figure 22: Traffic light display

5.1 'Traffic light' display

A 'traffic light' system is situated outside the LH2 control room which provides an indication of the system status en route to the main MICE Hall entrance. A key of relevant actions is provided adjacent to the system.

Table 3: Traffic light display actions

Display	System status	Action
Steady **green**	Gas detection operational No gas detected	OK to enter Hall
Flashing **green**	Gas detection operational Gas detected (will also show flashing amber or red)	See below
No **green**	Gas detection not operational	Do not enter Hall Contact Hydrogen Expert
Steady **amber**	Hydrogen operations in process (hydride bed charge, hydrogen fill & empty) PPS in Controlled Entry mode	OK to enter Hall using Controlled Access procedure See Section 3.1.1.2
Flashing **amber**	Gas alarm 25% - 50%	Do not enter Hall See Table 4
Steady **red**	System fault	Do not enter Hall Contact Hydrogen Expert
Flashing **red**	Gas alarm 50% +	Do not enter Hall See Table 4

5.2 Hydrogen detection

The control system displays the status of each detector pair on the '*Gas Det Alarms'* screen as follows:

- Gas panel enclosure - Box 3
- Plenum - Box 4
- Ventilation line - Box 7
- MICE Hall ceiling - Box 9
- Vac pump enclosure - Box 10

These correspond to channels on the gas detection controller (see Table 4).

Figure 23: Gas detection controller

Each detector has three alarm modes for 25%, 50% and 100% of Lower Explosive Limit of hydrogen. A trip on any detector will sound an alarm within the LH2 control room, while a trip in the gas panel enclosure or Hall will sound an additional alarm on the front of the gas panel and a trip in the vac pump enclosure will sound an additional alarm outside the enclosure building. The status of the 'traffic light' system will also change (see Section 5.1).

It should be noted that the detectors in the ventilation line (HC-HD03) are of a different design as they do not operate in air. As such, they will also detect helium.

- In the event of any hydrogen detector alarm, all personnel inside the MICE Hall, on the MICE roof or in the south wall area should be immediately contacted and evacuate to the MICE LCR. A Hydrogen Expert should view the '*Gas Det Alarms'* screen to determine the source of the alarm.
- Specific actions required for individual detector alarms are given in *Table 4: Hydrogen detection actions.*
    - '*Prohibit access to areas at risk'* means to collect and control all keys giving access the following areas:
        - MICE Hall
        - MICE Hall roof
        - South wall area (hydrogen vent lines)
    - '*Inform ISIS MCR'* means to dial **x6789** and alert the MCR to the alarm, recommending evacuation of the building if necessary. See Section 3.3.1 for the evacuation procedure.

Table 4: Hydrogen detection actions

Detector		Location	Action required	
Number	**Control screen box**	**Controller channels**		**Yellow (25% - 50%)**	**Red (> 50%)**
HC-HD02	3	1 & 3	Gas panel enclosure	Prohibit access to areas at risk, inform ISIS MCR.	Prohibit access to areas at risk, inform ISIS MCR. Consider evacuation.
HC-HD03	7	5 & 6	Ventilation line	Judge if intentional or not: - Intentional: mute alarm - Unintentional: restrict access, inform ISIS MCR	Judge if intentional or not: - Intentional: mute alarm - Unintentional: restrict access, inform ISIS MCR
HX-HD04	9	7 & 9	MICE Hall ceiling	Prohibit access to areas at risk, inform ISIS MCR. Consider evacuation.	Prohibit access to areas at risk, inform ISIS MCR. Consider evacuation.
HX-HD05	10	8 & 10	Vacuum pump enclosure	Judge if intentional or not: - Intentional: mute alarm - Unintentional: restrict access, inform ISIS MCR	Prohibit access to areas at risk, inform ISIS MCR. Consider evacuation.
HC-HD06	4	2 & 4	Ventilation plenum	Prohibit access to areas at risk, inform ISIS MCR.	Prohibit access to areas at risk, inform ISIS MCR. Consider evacuation.

5.3 Power failure

- In the event of a power outage, the system is passively safe. The control system and ventilation fans will operate for **2 hours** on the system UPS. If the power outage occurs during a sequence, the cryocooler, heater-chiller, vacuum pumps and purge pump will lose power and trip off.
- If hydrogen is in use, all personnel inside the MICE Hall, on the MICE roof or in the south wall area should be immediately contacted and evacuate to the MICE LCR.
    - A Hydrogen Expert should be contacted to determine whether it is safe to manually switch the system back on once the power supply has been restored.

5.4 Control system failure

- In the event of a PLC failure, touch screen malfunction or loss of control due to manual intervention, the system is passively safe.
- If hydrogen is in use, all personnel inside the MICE Hall, on the MICE roof or in the south wall area should be immediately contacted and evacuate to the MICE LCR.
    - A Hydrogen Expert should be contacted to determine the root cause of the failure and decide on a suitable course of action.

5.5 Purge gas supply failure

- In the event of a nitrogen supply failure, the system should be left in whatever state it currently is and a Hydrogen Expert should be contacted to restore nitrogen flow as soon as possible.

5.6 Vacuum failure

- In the event of a gradual vacuum failure, the control system will react accordingly; no operator intervention is required.
- In the event of a catastrophic vacuum failure, all personnel inside the MICE Hall, on the MICE roof or in the south wall area should be immediately contacted and evacuate to the MICE LCR.
    - A Hydrogen Expert should be contacted to determine the root cause of the failure and decide on a suitable course of action.

5.7 Fire in the MICE Hall

A fire in the MICE Hall should be treated in the same manner as a fire anywhere. The hydrogen system should be left in whatever state it currently is and a Hydrogen Expert contacted immediately.

6 Contact details

6.1 Hydrogen Experts

- **Steve Watson** – LH2 system manager
  x6331 (office) / x1188 (mobile)
  1.15, R66 (RAL)
- **Phil Warburton** – LH2 control engineer
  x3882 (office)
  B1 (DL)
- **Mike Courthold** – LH2 cryogenic engineer
  x6462 (office) / 07770-652507 (mobile)
  1.11, R65 (RAL)

6.2 Other contacts

- **ISIS Main Control Room**
  x6789
- **Andy Nichols** – MICE project manager
  x5251
- **Vicky Bayliss** – MICE cryogenics engineer
  x7017
- **Tom Bradshaw** – Cryogenics Group Leader
  x6149
- **Ian Mullacrane** – MICE electrical infrastructure
  x3403
- **John Govans** – ISIS services manager (chillers, compressors, water supply)
  x6012
- **Stewart Greenall** – MICE Hall manager
  x1309

7 Appendices

7.1 System checklists (overleaf)

Pre-sequence check list 1

Applicable to following sequences:

- *Standard helium purge ("He Purge Sq")*
- *Helium supply line purge ("He Line Pur Sq")*
- *Helium fill*
- *Helium empty*

Note: This checklist should only be used in conjunction with the system Operating Instructions.

Control system and instrumentation

Control screen OK	
Air supply OK	

Cryogenic system

Visual checks	
Cryocooler OK	
Compressor OK	

Gas panel enclosure

Visual checks	
HV31 open and locked	

Ventilation system

Visual checks	
Cabinet gate valve shut	
Fans OK	

Purge gas supply

Bottle pack pressure > 100 barg	
Bottle pack regulator set to ~3 barg	
HV16 open + PG01 = 1350-1450 mbar	

Vacuum system

Vac pump oil OK	
Turbo pump OK	
PV20 open	

Pre-sequence check list 2

Applicable to following sequences:

- *Hydrogen-side purge ("He Pur H2 Sq")*
- *Hydrogen fill*
- *Hydrogen empty*

Note: This checklist should only be used in conjunction with the system Operating Instructions.

Control system and instrumentation	
Control screen OK	
Air supply OK	
Penning gauges unplugged	
Cryogenic system	
Visual checks	
Cryocooler OK	
Compressor OK	
Gas panel enclosure	
Visual checks	
HV31 open and locked	
Ventilation system	
Visual checks	
Cabinet gate valve shut	
Fans OK	
Purge gas supply	
Bottle pack pressure > 100 barg	
Bottle pack regulator set to ~3 barg	
HV16 open + PG01 = 1350-1450 mbar	
HV15 open + FM5 = ~2 l/min	
Vacuum system	
Vac pump oil OK	
Turbo pump OK	
PV20 open	
Heater-chiller	
Auxiliary chiller OK	
Heater-chiller OK	
Miscellaneous	
Oxygen cylinders and oxy-acetylene sets removed	

Pre-sequence check list 3

Applicable to following sequences:

- Hydride bed charge

Note: This checklist should only be used in conjunction with the system Operating Instructions.

Control system and instrumentation	
Control screen OK	☐
Air supply OK	☐
Penning gauges unplugged	☐
Gas panel enclosure	
Visual checks	☐
Ventilation system	
Visual checks	☐
Cabinet gate valve open	☐
Fans OK	☐
Purge gas supply	
Bottle pack pressure > 100 barg	☐
Bottle pack regulator set to ~3 barg	☐
HV16 open + PG01 = 1350-1450 mbar	☐
HV15 open + FM5 = ~2 l/min	☐
Vacuum system	
Vac pump oil OK	☐
Heater-chiller	
Auxiliary chiller OK	☐
Heater-chiller OK	☐
Miscellaneous	
Oxygen cylinders and oxy-acetylene sets removed	☐

Pre-sequence check list 4

Applicable to following sequences:

- *Vac-down procedure*

Note: This checklist should only be used in conjunction with the system Operating Instructions.

Control system and instrumentation

Control screen OK	
Air supply OK	

Vacuum system

Vac pump oil OK	
Turbo pump OK	
PV20 open	

Shift worker instructions (MICE LH2 R&D programme)

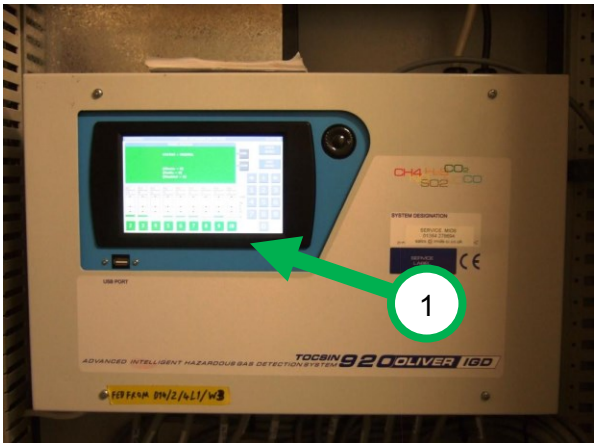
As a shift worker, your responsibilities extend to only observation under normal working conditions. The system is in an inherently untested state and so should only be interacted with by a Hydrogen Expert or under a Hydrogen Expert's instruction.

- When starting and finishing your shift:
  - Sign the log book
  - Ensure the shifter key is handed over to the on-shift workers
- Check in with ISIS MCR midway through your shift, either in person or by phone on x**6789.**
- Use the whiteboard provided to note any of the following:
  - Unexpected system performance changes
  - Actions taken
  - Comments or suggestions regarding Operating Instructions
  - Any other observations
- **Above all, if in doubt, contact a Hydrogen Expert.**

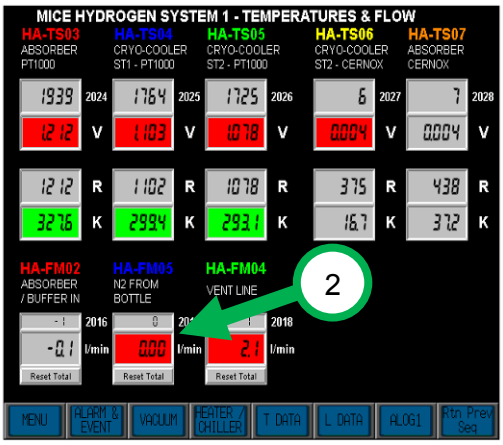
Control room | Inside Hall | Outside Hall

Shift check list

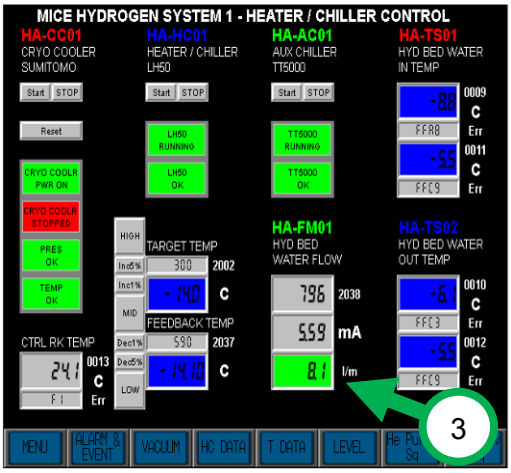
	Check	Expected value	Logged value
1	Max gas detection level	<12% any channel	
2	Nitrogen flow rate (**FM5**)	~2 litres / min	
3	Glycol flow rate (**FM1**)		
4	Nitrogen bottle pack pressure		
5	Helium bottle pack pressure	<2.2 MPa	
6	Compressor pressure		
7	Glycol level	1 - 5 bars	
8	Aux chiller temperature	<30 °C	



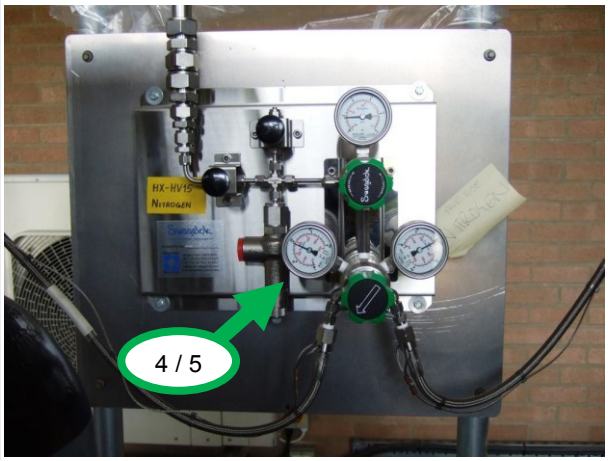
Gas detection controller



N2 flow rate on 'Temp' screen



Glycol flow rate on 'Heater/chiller' screen



Purge gas regulator panels

Compressor pressure gauge

Aux chiller and heater-chiller displays